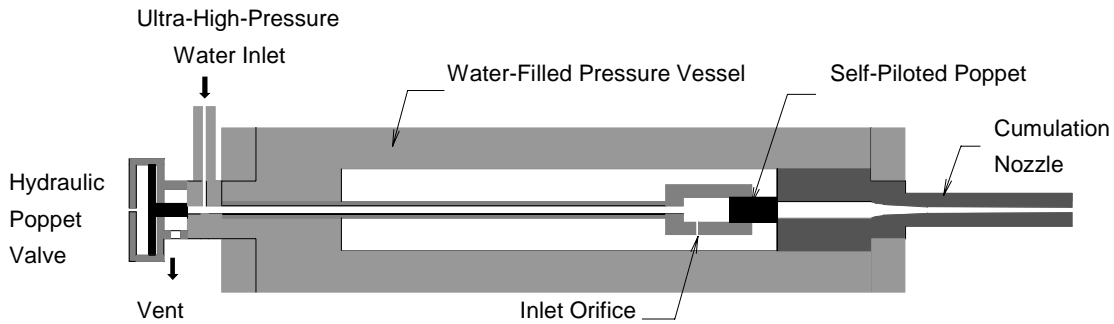


Ultrahigh Pressure Pulse Water Jets for Mine and IED Neutralization

Navy Need and Payoff

This proposal addresses a non-explosive technology for cutting and penetrating, with immediate applications to mine and improvised explosive device (IED) neutralization, whether underwater or above. The basic concept is to produce containers of ultrahigh pressure liquid which, on release, would form an intense jet capable of penetrating substantial metal thickness to flood or destroy mine fuzing. Because the jet velocity is extremely high, this technology may also be successful in neutralizing IED's fused with membrane switches and in penetrating hard cases typical of sea mines or pipe bombs. The need for neutralization methods is identified in a Command Technology Issue (CTI), "Passive Shallow Water/Terrestrial Mine, Explosive and Booby-Trap Detection and Neutralization," while the need for improved methods of neutralization is identified as another CTI, "Advanced Munitions." Projects supporting these CTI's have relied on explosive munitions which, while effective, suffer by being extremely overt, and introduce significant issues related to transportation, storage, handling and accountability for explosive materials. This non-explosive system will perform functions quite similar to those currently performed with the JROD or the caliber .50 dearmers, and will be comparable in size and weight. The ultrahigh pressure waterjet system has numerous advantages when used underwater, as there is no gas evolution, and a comparatively minor lateral pressure field. This means that divers may be safe in the vicinity of the cutting operation, that nearby devices and organisms will be relatively unaffected, that the system will be depth-insensitive, and it means that the entire operation will be far more covert than one which involves gas generation. Several other applications are envisioned, where relatively quiet operation, leaving an inconspicuous penetration, would be useful. The ability to perform these operations in a covert manner will open tactical options not previously available.

An ultrahigh pressure waterjet piercing tool is shown in the sketch below. Preliminary estimates for this tool would have it deliver 4 kJ of energy, weigh about 12 kg. and be able to produce a 10 mm diameter hole. The size and weight of the tool will scale with the area of the hole. The energy is stored by compressing the water to 400 MPa; at this pressure water compresses by about 13%. The pressure would be released by unloading the back side of a self-piloted poppet. The ultrahigh pressure acting on the front side of the poppet lifts it extremely rapidly, allowing the stored volume to discharge as a pulse. An 18:1 cumulation nozzle will boost the dynamic pressure from 400 MPa at the inlet to 7.2 Gpa (1 million psi) at the exit. This pressure should easily pierce 6.35 mm mild steel sheet. The Voitsekhovskiy cumulation nozzle design is based on constant pressure driving a slug of water (Voitsekhovskiy 1967). As the water fills enters the tapered nozzle, the leading edge accelerates because of conservation of mass, while the trailing edge decelerates to conserve momentum. An exponential curve form for the nozzle taper leads to a maximum energy transfer.



**Conceptual Sketch of a Rechargeable Waterjet
for IED and UXO Disruption**

Technical Approach

The Coastal Systems Station will undertake this project as a joint effort with Tempres Technologies in Kent, WA. Our experience with EOD and SOF diving operations, mine countermeasures, and acoustic field measurement complements Dr. Kollé's recognized expertise in ultrahigh pressure water blasting. The Dynamic Fluid Systems Laboratory at Tempres Technologies incorporates ultra-high-pressure pulse generator and pumping equipment as well as ballistic pressure instrumentation required to carry out the development work.

Important program elements address the mechanics of penetration and its implementation in a field useable system:

a) **Cumulation Nozzle Design:** Achieving pressure amplification through a cumulation nozzle is a proven technology; an optimal design for our applications will be developed under this task. Related components, such as the sealing disc and release mechanism for underwater applications will be studied under this task, as well. Using Tempres's research facility, nozzle design parameters will be studied to ensure peak energy transfer.

b) **Penetration Parameters:** Initial experiments will establish the penetration achievable, as a function of charge energy (stored pressure and volume), hole diameter (a function of nozzle design), slug size, and the material being penetrated. This task interacts with the cumulation nozzle design task. Existing penetration models will be evaluated against experiment, and design parameters for neutralizing selected mine types will be developed. During this phase, a wide variety of materials will be examined, to validate the penetration model and to lay a foundation for future applications.

c) **Pressure Vessel:** Pressure vessel design will maximize stored energy with minimum weight and volume. The steel vessel shown above is expected to weigh about 20 pounds, but we estimate that this weight can be cut to about 7 pounds using a composite cylinder which will also minimize the device's magnetic signature. Before

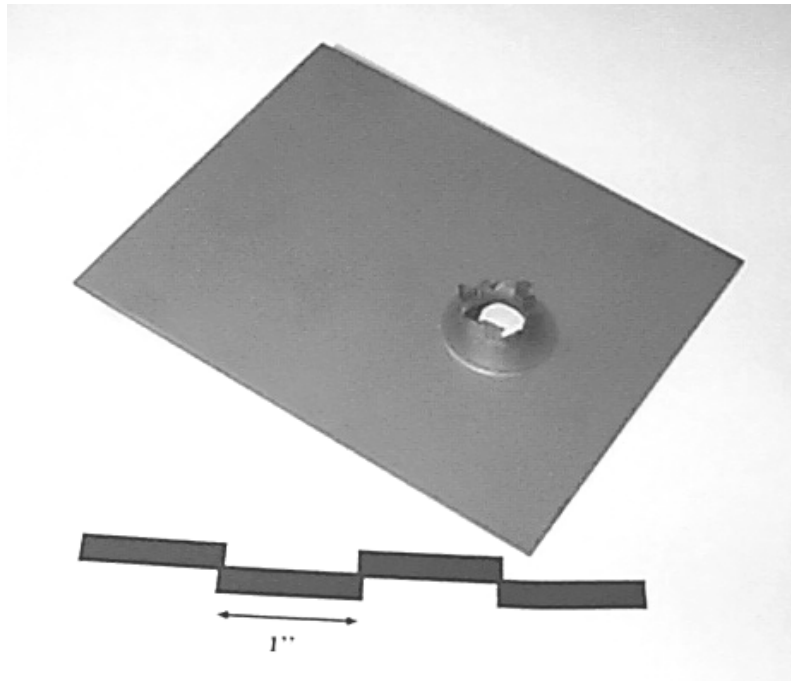
finalizing a steel or composite pressure vessel design, the impact on safety and performance and cost will be reviewed. Techniques for loading and pressurizing the tool will be developed under this task.

d) External Pressure Field: The pressure field induced outside the tool, when used underwater, will be studied to develop safety standards for divers in the vicinity of the tool, and to determine the detectability of its operation.

e) Triggering Mechanisms: While the device pictured above shows a fast-acting poppet valve, several other means are available for achieving nearly instantaneous release of the high pressure water (rupture discs, for instance). We would anticipate actuating the device by conventional means (pilot, electrical solenoid, acoustic release, etc.). This phase of the project will be coordinated with EOD technical personnel to develop the most field-usable configurations.

Expected Performance

Based on small scale experiments, theoretical work, and large-scale industrial systems, we anticipate that an easily deployed ultrahigh pressure waterjet system will be capable of penetrating up to 1/4" steel cases to produce a hole between 1/4" and 1/2" in diameter. The waterjet velocity will be above 700 m/s (2300 feet/sec.), perhaps as high as 1400 m/s (almost 5000 fps), and will be able to "beat" most fuzing switches. The system, exclusive of the charging intensifier, will weigh less than 25 lbs., perhaps as little as 10 lbs. for penetrating thin sheet metal or plastic cases. The charging intensifier will weigh less than 25 lbs. and be able to recharge a 0.2 liter system in about one minute. The photo below shows test results on a steel test plate penetrated by a jet produced from water pressurized to 44000 psi.



Test results showing penetration of 1/8" steel plate by an ultrahigh pressure waterjet

Relationship to Other Efforts

Recognizing the danger to divers in the vicinity of an underwater explosion, and problems as basic as ensuring that explosive neutralization devices stay in position as each of several neutralization events occurs, several projects support the CTI's identified earlier. One such project addresses remote actuation technology, both acoustic and electromagnetic. (SOTD/ARPA project sponsored by W. Williams/CAPT. B. Dyer; project leader is Tim Pride, CSS). Present technologies involve explosive detonation, which derives its power from expanding gas; the associated hazards to divers and sealife, as well as the overt nature of this process, are undesirable. The use of ultrahigh pressure water will considerably reduce both risk and detectability. Further, if the process proves to be sufficiently covert, neutralization could be accomplished at any time prior to insertion, without compromising tactical options.

Deliverables

Report on penetration performance	8 months
Report on external pressure field	12 months
Prototype ultrahigh pressure waterjet system	18 months
Demonstration on selected mines and IED's	22 months
Final Report	24 months

Estimated Cost

FY98: \$290K

FY99: \$390K

Total: \$680K

References

- Kollé, J. J. (1994) "Development and Applications of a Hydraulic Pulse Generator," *Mechanical Engineering*, **116 (5)**, 81-85.
- Voitsekhovsky, B.V. (1967) "Jet nozzle for obtaining high pulse dynamic pressure heads," U.S. Patent 3,343,794.
- Walters, W.P., W.J. Flis and P.C. Chou (1988) "A survey of shaped-charge jet penetration models," *Int. J. Impact Eng.*, **7 (3)**, 307-325.

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Dr. Kollé directs the Dynamic Fluid Systems laboratory at Tempress Technologies Inc. (<http://www.tempresstech.com/>). The company is pursuing commercial development of pulsed jet systems for manufacturing, oil & gas development, mining and civil engineering. He was previously employed as a Senior Research Scientist with QUEST Integrated Inc., where he was responsible for establishing and directing research programs in the areas of drilling mechanics, microstructural modeling of materials, development of advanced drilling and excavation systems and manufacturing applications of pulsed water jets. Dr. Kollé developed the hydraulic pulse generator and holds three patents on its design. He has authored over thirty five papers on subjects ranging from iceberg towing to sediment acoustics. A list of his publications related to pulsed jet systems and offshore engineering is provided below

Relevant Publications

1. Kollé, J. J. (1983) "A New Technique for Controlled Small-Scale Hydraulic Fracturing," *Proceedings of the 1st International Symposium on Rock Fragmentation by Blasting*, Luleå University of Technology, Luleå, Sweden, Vol. 3.
2. Kollé, J. J., and Fort, J. A. (1989) "Application of Dynamic Rock Fracture Mechanics to Non-Explosive Excavation," *Proceedings of the 29th U.S. Symposium on Rock Mechanics*, Minneapolis.
3. Kollé, J. J., and Hashish, M. (1989) "Recent Developments in High-Pressure Technology for Mining and Drilling," invited paper Mining Geomechanics '89, Ostrava, Czechoslovakia.
4. Kollé, J. J. (1990) "Moving an Ice Mountain," *Mechanical Engineering*, pp. 48-53, February.
5. Kollé, J. J., Otta, R., and Stang, D. L. (1991) "Laboratory and Field Testing of an Ultrahigh-Pressure Jet-Assisted Drilling System," *Proceedings of the 1991 SPE/IADC Drilling Conference*, Paper No. SPE/IADC 22000, Amsterdam, pp. 847-56.
6. Bibee, L. D. and Kollé, J. J. (1993) "Seismic Penetrator Technology for Use in Shallow Water Seismoacoustics," *Proceedings from OCEANS '93*, Victoria, British Columbia.

7. Kollé, J. J. (1993) "Effects of Dynamic Confinement on Drilling in Pressurized Boreholes," *International Journal of Rock Mechanics and Mining Science*, Vol. 30, No. 7, pp. 1215-18.
8. Kollé, J. J. (1993) "Low-Cost Drilling for Characterizing Marine Gas Hydrate Accumulations," *Proceedings of the Fourth International Offshore and Polar Engineering Conference*, Osaka, Japan, 1994.
9. Kollé, J. J. (1994) "Development and Applications of a Hydraulic Pulse Generator," *Mechanical Engineering*, **116 (5)**, 81-85.
10. Adamson, J.E. and J.J. Kollé (1996) "Development of a waterjetting cable burial system for a broad range of soils in up to 2500 meters of seawater," *Proceedings of Underwater Intervention '96*, New Orleans, 4-10, Marine Technology Society, Washington, DC.
11. Kollé, J.J. (1997) "Pulsed waterjet soil perforation for in-situ remediation," *In-Situ and On-Site Bioremediation; the Fourth International Symposium: Volume.5*, proceedings of the Fourth International In Situ and On-Site Bioremediation Symposium, pp. 541-546, New Orleans, April 28 - May 1.
12. Kollé, J.J. (1997) "Hydraulic pulse generator for non-explosive excavation," *Mining Engineering*, July, 1997, 64-72.
13. Veenhuizen, S.D., J.J. Kollé, C.C. Rice and T.A. O'Hanlon (1997) "Ultra-high pressure jet assist of mechanical drilling," SPE 37579, *Proceedings of the 1997 SPE/IADC Drilling Conference*, Amsterdam.
14. Kollé, J.J. (1998) "A comparison of water jet, abrasive jet and rotary diamond drilling in hard rock," proceedings Energy Technology Conference and Exhibition, Houston, February 2-4, ASME International, New York.
15. Kollé, J.J. (1998) "Civil engineering applications of compressed water cannons" *Waterjet Applications in Construction Engineering*, edited by A.W. Momber, Balkema, Rotterdam, 1998.

Patents

1. Kollé, J. J. (1987) "Process and Apparatus for Fragmenting Rock and Like Material Using Explosion-Free High-Pressure Shock Waves," U.S. Patent No. 4,669,783, June 2.
2. Kollé, J. J. (1989) "Highly Reliable Method of Rapidly Generating Pressure Pulses for Demolition of Rock," U.S. Patent No. 4,863,220, Sept. 5.
3. Kollé, J. J., and Monserud, D. O. (1991) "Apparatus for Rapidly Generating Pressure Pulses for Demolition of Rock Having Reduced Pressure Head Loss and Component Wear," U.S. Letters Patent No. 5,000,516, March 19.

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Dr. Mittleman is a research mechanical engineer at the Naval Surface Warfare Center, Dahlgren Division, Coastal Systems Station. He has been actively involved with the development of hydraulic tools and inspection systems for divers since 1971, including the use of high pressure water jets for soil excavation and hull cleaning. He has authored numerous reports and journal articles dealing with underwater nondestructive testing and hydraulic tools for underwater repair and maintenance, and holds seven patents in the field.

Selected Publications

- (1) Craven, J.P., T. Gray Curtis, John Mittleman, and J. Patgell, "Ocean Engineering Systems," Massachusetts Institute of Technology Press, 1971, Sea Grant Report #MITSG71-6.
- (2) Mittleman, J. and M. Hura, "High Capacity Oil/Water Separator," The Naval Engineer's Journal, Vol. 89, No. 6, December 1977.
- (3) Jolliff, CAPT James V. (USN) and John Mittleman, "The Role of Navy RDT&E Centers in Diving and Salvage Technology," NAVSEA Journal, Vol. 28, No.4, June 1979.
- (4) Mittleman, J. and D. Wyman, "Underwater Ship Hull Examination," presented to ASNE Day '80, Washington, D. C., May 1-2, 1980, published in The Naval Engineer's Journal, Vol. 92, No. 2, April 1980.
- (5) Jolliff, CAPT James V. (USN) and John Mittleman, "Cold Oil Salvage Pumps," presented to ASNE Day '80, Washington, D. C., May 1-2, 1980, published in The Naval Engineer's Journal, Vol. 92, No. 2, April 1980.
- (6) Goldberg, Lawrence and J. Mittleman "Underwater Magnetic Particle Testing," section 16, part 1 of "Nondestructive Testing Handbook, 2nd Ed. (Volume 6 - Magnetic Particle Testing)" edited by Paul McIntire, American Society of Nondestructive Testing, 1989.
- (7) Mittleman, John, " Comparison of Inspection Procedures," Materials Evaluation, V. 48, No. 2, February 1990
- (8) Mittleman, John, "Computer Modeling of Underwater Breathing Systems," Undersea and Hyperbaric Medical Society publication #76-UNDBR, 1 OCT 89

- (9) Mittleman, John and L. Goldberg, "Ultrasonic Inspection of Offshore Structures," in Nondestructive Testing Handbook, Second Edition, Volume Seven, Ultrasonic Testing (pp. 690-700), P. McIntire (Editor), Am. Soc. for Nondestructive Testing, 1991
- (10) Mittleman, J. and Swan, L.K. (1993) "Underwater Inspection for Welding and Overhaul," Naval Engineers Journal, Vol.105, No.5, pp. 37-42
- (11) Mittleman, J., Roberts, R., and Thompson, R.B. (1995) "Scattering of Longitudinal Elastic Waves from an Anisotropic Spherical Shell," Journal of Applied Mechanics, V62:1, pp. 150-158
- (12) Mittleman, J., Thompson, R.B., and Han, Y.K. (1996) "Elastic Wave Scattering by Shelled Spherical Scatterers in a Focused Field," J. Acoust. Soc. Am. 99(5), pp. 2862-2870 (May 1996)

Patents

- (1) #3,849,996 Method and Apparatus for Positioning a Cofferdam
- (2) #4,133,204 Roughness Diagnostic Tool
- (3) #4,191,461 Camera Jig for Underwater Stereoscopic Photography
- (4) #4,207,450 Continuous Oil/Water Monitor
- (5) #4,388,593 Magnetic Portable Inspection Device
- (6) #4,305,522 Ultrasonic Pit Depth Gauge
- (7) #5,311,126 Magnetic Field Strength Threshold Indicator for Use in a Magnetic Particle Inspection Device